

1        **DELAY BASED SPACE AND TIME COORDINATED REPEATER SYSTEM**

2  
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4

5                    **Field of the Invention**

6            **[001]**        The field of the invention relates to Radio  
7        communications, and more particularly to synthetic aperture  
8        antenna systems and tapped-delay-line signal enhancement  
9        techniques. More specifically, the invention relates to a  
10       method and apparatus for utilizing a dynamically configured  
11       array of repeaters to facilitate multiple point-to-point  
12       communication links.  
13

14                   **Background of the Invention**

15           **[002]**        Ever since radio transmission first became a  
16       reality, utilization of the electromagnetic (EM) spectrum  
17       for communication has continued to grow. Every part of the  
18       electromagnetic spectrum from AM radio up through infrared  
19       and visible light is now used to transmit information.  
20       Modern consumer devices which transmit and/or receive EM  
21       signals include FM and AM radios, CB and personal radios,  
22       televisions, pagers, cell phones, remote controls for  
23       consumer electronics, GPS receivers, PDAs, cordless phones,  
24       wireless local area networks, wireless computer  
25       peripherals, garage door openers, wireless door bells,  
26       wireless home and car burglar alarm components, etc. New  
27       low-power EM communication standards such as Bluetooth are  
28       resulting in a new generation of consumer electronics such  
29       as video cameras, VCRs and the like which can all  
30       communicate wirelessly.

31           **[003]**        In an attempt to minimize interference  
32       between wireless devices, while having as many devices make

1 use of the available EM spectrum as possible, countries  
2 such as the United States have enacted complex laws and  
3 regulations specifying the types of use for different  
4 portions of the EM spectrum (including geographic and power  
5 limitations), and in some cases requiring licensing of  
6 classes of transmitters or individual transmitters.

7       **[004]**       Various technologies have been developed  
8 over time to allow different parts of the EM spectrum to be  
9 utilized by more devices simultaneously. While early  
10 applications of EM communication (such as radio and  
11 television broadcasts) assumed by default that the  
12 transmitter would be omnidirectional (so it could reach  
13 listeners in every direction) and the receiver would be  
14 omnidirectional (so it would be cheap and simple to use),  
15 and that the transmission of information from the  
16 originating transmitter to the final receiver would take  
17 place in one step, setups like that severely limit the use  
18 of the EM spectrum as compared with what is possible when  
19 other techniques (such as directional antennas and/or  
20 repeaters) are employed.

21       **[005]**       Many of the challenges that exist in the  
22 efficient utilization of the EM spectrum (both across  
23 frequency and across geographic space) have analogs in  
24 acoustics. Many people trying to talk to each other in a  
25 restaurant at the same time produces an environment with  
26 significant background noise. People at first try to  
27 compensate by talking louder. With everyone talking  
28 louder, the background noise gets even louder. Finally,  
29 people have to lean closer to each other to talk. In the  
30 end, people are leaning closer as well as shouting, whereas  
31 if everyone had been leaning closer to begin with, the  
32 shouting would not have been necessary. Perhaps one reason

1 governments regulate EM transmission power is to avoid the  
2 same "escalation" in the EM domain, and drive technology  
3 toward more efficient solutions for point-to-point  
4 communication.

5       **[006]**       The shape of the human head and the  
6 placement of the ears allow a person to listen  
7 directionally and pick out one of many nearby  
8 conversations. Analogously, the utilization of directional  
9 receivers and/or transmitters has allowed better  
10 utilization of the EM spectrum. For example, a modern cell  
11 phone tower can broadcast to several cell phones  
12 simultaneously on the same channel, in different physical  
13 directions, and the direction of each communication can be  
14 varied over time as the people using cell phones move  
15 around (typically on foot or in cars). Likewise, satellite  
16 receivers may be pointed individually at any one of a  
17 number of orbiting satellites operating in the same  
18 frequency band.

19       **[007]**       In the cell phone application, the transmit  
20 and receive patterns of the cell phone tower antenna are  
21 highly directional and varied under computer control, while  
22 the transmit and receive patterns of the consumer's cell  
23 phone are omnidirectional (so the consumer doesn't have to  
24 know where the tower is or point the cell phone at the  
25 tower). The directionality of the cell tower antenna not  
26 only allows the tower to communicate with more cell phones  
27 simultaneously in a given portion of the EM spectrum, it  
28 also allows the transmitters in the cell phones to operate  
29 at lower power, because the directionality results in an  
30 increase in received signal-to-noise ratio when the cell  
31 tower antenna is operating as a receiver. This increase in  
32 signal-to-noise ratio is sometimes referred to as antenna

1 "gain". In transmit mode, because the directionality of  
2 the antenna concentrates the transmitted RF power in a  
3 particular direction, the signal intensity in that  
4 direction is effectively amplified. In receive mode,  
5 although directionality does not result in an increase in  
6 received signal, it is effectively a gain (in signal-to-  
7 noise ratio) because the antenna directionality results in  
8 a reduction in noise.

9       **[008]**       As the EM spectrum becomes more heavily  
10 utilized, more and more EM "noise" is present in our  
11 environment. Any EM signals that come from transmitters  
12 other than the one we are trying to receive from shall in  
13 this document be referred to as noise. In addition to  
14 noise, in an urban environment, for example, where metallic  
15 objects may reflect EM transmissions, the problem of  
16 "multi-path" must also be dealt with. Multi-path occurs  
17 when two versions of the same signal arrive at a receiver  
18 through pathways of different lengths. If the difference  
19 in lengths of the two paths is short compared to the EM  
20 wavelength of the highest frequency information which is  
21 modulated onto the carrier, but long enough to represent at  
22 least a significant fraction of the wavelength of the  
23 carrier itself, then multi-path can result in destructive  
24 interference at the carrier level. The probability density  
25 function in Figure 9 illustrates the relative likelihoods  
26 that two waves arriving at an antenna with equal field  
27 strength and randomly aligned phase would sum to a  
28 composite field strength between zero and two. If one of  
29 the two pathways involves reflection of the EM signal off a  
30 moving object, loss of signal (caused by destructive  
31 interference) may come and go over time.

1           **[009]**       If the difference in lengths of the two  
2 paths is long compared to the EM wavelength of the highest  
3 frequency information which is modulated onto the carrier  
4 (such condition shall herein be referred to as Long Multi-  
5 path), ghosting of the demodulated signal will occur, such  
6 that the actual demodulated signal comprises two time-  
7 shifted versions of the intended demodulated signal (where  
8 the two time-shifted components usually also have different  
9 amplitudes). The effect of such multi-path is commonly  
10 observable as "ghost" image artifacts in broadcast TV  
11 images received in urban environments.

12           **[0010]**     Making the receiving antenna highly  
13 directional significantly reduces most sources of multi-  
14 path, since in most cases the EM signals that arrive at the  
15 receiving antenna do not wind up coming from the same  
16 direction. Directional receiving antennas can be a  
17 practical solution to improving broadcast TV reception  
18 (witness the availability of roof-top TV antennas and  
19 associated servo-mechanisms to rotate such antennas under  
20 remote control), but as illustrated in the cell phone  
21 example, directional receiving antennas may not be a  
22 practical solution in an application where either the  
23 transmitter or the receiver is mobile.

24           **[0011]**     Different technologies have been developed  
25 to deal with Long Multi-path in the signals received on the  
26 omnidirectional antennas of cell phones and TV sets. One  
27 technique used in some TV sets involves subtracting an  
28 amplitude-adjusted version of demodulated signal from the  
29 demodulated signal, such that the ghost phenomenon is  
30 eliminated to first order. This is done by passing the  
31 composite received signal through a Finite Impulse Response  
32 (FIR) filter with dynamically adjustable coefficients.

1           **[0012]**     Another technique (used in cell phones)  
2 involves shifting the received RF signal down to an  
3 intermediate frequency (IF), and then sampling the IF and  
4 using a multi-tapped FIR filter (sometimes referred to as a  
5 "rake filter") to effectively constructively align the  
6 arrival times of the various multi-path signals. This is  
7 usually done as part of the overall Digital Signal  
8 Processing (DSP) performed in the cell phone. Self-  
9 adjusting DSP algorithms have been developed whereby cell  
10 phones monitor and dynamically compensate out the effects  
11 of Long Multi-path interference.

12           **[0013]**     It has already been mentioned that highly  
13 directional antennas comprise one method for reducing the  
14 amount of power needed to transmit over a given distance  
15 from a transmitter to an intended receiver (thus reducing  
16 EM "pollution" or noise at unintended receivers). Another  
17 method of reducing the required amount of transmit power is  
18 to utilize repeaters. In the acoustic analog of the  
19 crowded restaurant with many conversations going on, one  
20 might think of two ways of communicating with a person on  
21 the other side of the room. One way would be to stand up  
22 and yell, and another way would be to ask a series of  
23 people to pass a verbal message along until the message  
24 reaches the intended recipient.

25           **[0014]**     The power needed to produce a given field  
26 strength at a given distance in the far field of an  
27 omnidirectional transmitter grows with the square of the  
28 distance. Thus, dividing the distance the signal is to be  
29 transmitted into co-linear sequential segments reduces not  
30 only the power required at each sequential (repeater)  
31 transmitter, but also reduces the summed total power of the  
32 sequence of transmitters. That is, the summed total power

1 of the sequence of transmitters is less than the power  
2 needed to transmit the signal the entire distance using a  
3 single transmitter. Repeaters have long been used to  
4 reduce the power needed to transmit communications signals  
5 from remote areas. Repeaters can also be used to transmit  
6 "around" obstructions. For instance, a series of repeaters  
7 can be used to transmit a line-of-sight EM signal over or  
8 around a mountain.

9       [0015]     A series of repeaters may be considered to  
10 be a multiple-discreet-element wave guide arranged in  
11 space. The series of repeaters guides a signal along a  
12 path in a way analogous to a wire or a fiber-optic cable  
13 guiding an EM signal along a path, by concentrating the  
14 propagation of that signal in a volume of space along the  
15 path, rather than having the signal propagate equally in  
16 all directions. In a military application, it may be  
17 desirable to use a series of repeaters to route a  
18 transmitted signal around an enemy, such that at the  
19 location of the enemy, the transmitted signal is too weak  
20 to receive.

21       [0016]     While utilization of dedicated repeaters  
22 certainly aids in efficient point-to-point transmission of  
23 EM signals, this solution is not without its own drawbacks.  
24 Such drawbacks include the cost incurred to manufacture,  
25 geographically locate, and maintain an entire series of  
26 transceivers, rather than just two. In a cell-phone-to-  
27 cell-phone conversation, cell phone towers essentially act  
28 as ground-linked repeaters for passing along information  
29 transmitted from one cell phone to another. Thus while the  
30 cost in terms of total EM transmit power is lower, the cost  
31 in terms of producing and maintaining equipment may be  
32 high.

1           [0017]     Most cell phone users are familiar with  
2     certain geographic areas where cell phone coverage "drops  
3     out". Usually at times of highest system utilizations  
4     (such as morning and evening commuting times), the drop-out  
5     zones become larger and more frequent.

6           [0018]     Indeed, in both civilian and military  
7     applications, it is often true that the times when more  
8     ground-based repeaters and more ground-based-repeater  
9     capacity is most needed are at times of highest system  
10    utilization. In disaster situations the need for more  
11    capacity becomes particularly acute. These situations  
12    include "acts of god" such as earthquakes or fires in  
13    places such as California, hurricanes in places such as the  
14    southeastern states, as well as situations such as the  
15    terrorist attacks of September 11, 2001 during which the  
16    cellular phone system became so overloaded it was virtually  
17    useless to emergency personnel.

18          [0019]     In view of the foregoing, a need clearly  
19    exists for self-configuring communications systems that  
20    utilize their own dynamically shifting matrix of receive  
21    and transmit nodes to route wireless communication signals  
22    in areas where no ground stations have been set up. This  
23    need exists both for military applications and for civilian  
24    applications. Such a military communication system should  
25    utilize the entire array of transceivers carried by  
26    military personally in a combat operation as nodes on a  
27    dynamically configurable repeater system. Such a civilian  
28    communication system is needed, for instance, to  
29    automatically fill in "holes" in cellular coverage (where  
30    tower antennas provide inadequate coverage) by routing  
31    calls through other cell phones (which are equipped with  
32    the present invention).



## Summary of the Invention

[0020] The present invention utilizes an array of personal communication devices such that each device is not only an end point for a given point-to-point communication, but also a repeater for a plurality of other point-to-point communications. Each point-to-point communication may take multiple simultaneous paths. Figure 5 illustrates a matrix of transceivers 500, and the multiple paths taken through that matrix by communication from transceiver 501 to transceiver 502 (through repeater set 507), and from transceiver 503 (through repeater set 506) to transceiver 504. Within Figure 5, all the arrows coming in to any node represent RF signals from nearby repeaters. In a preferred embodiment, digital signal processing of multiple delayed versions of signals received at each receiver is employed to enhance signal-to-noise ratio by constructively correlating signals propagating along multiple paths through the array of repeaters. Although the two propagation paths shown in Figure 5 do not cross, the present invention allows them to cross (utilize common nodes) should that be desired.

[0021] In the preferred embodiment, both data (the information being communicated between users) and control signals propagate through the repeater array. Control signals may take different paths through the repeater array than the data, since the routing of the data both control and data information may be separately controlled. Preferably, each repeater contains digital means to provide a separately controllable delay to each signal that it retransmits (or repeats). These controllable delays are separately and dynamically reconfigurable.

1           **[0022]**     The repeaters in the array are not dedicated  
2 repeaters, but rather serve both a repeater function as  
3 well as their intended end-point communication function  
4 (such as being a cell phone). Although transceivers in the  
5 array depicted in Figure 5 are regularly spaced, regular  
6 spacing is not a requirement according to the present  
7 invention, and in fact it is recognized that in many  
8 applications each transceiver in the array would be mobile,  
9 and in motion during use. Since each device may be and  
10 often will be mobile, its position will not be known well  
11 enough to allow dynamically adjustable delays to provide  
12 multi-path communication which provides constructive signal  
13 correlation at the carrier level (such as that provided by  
14 a directional antenna), rather the present invention  
15 provides correlation between multiple communication paths  
16 which provide constructive reinforcement of the signals  
17 being transmitted on the carriers. In the preferred  
18 embodiment of the present invention, constructive summation  
19 of multi-path communication is performed at an intermediate  
20 frequency (IF) through summing multiple outputs of a tapped  
21 digital delay line as illustrated in Figure 7.

22           **[0023]**     In an alternate embodiment, constructive  
23 summation and/or correlation of multi-path communication  
24 may be performed after demodulation (detection).  
25 Optionally, re-coding may be employed prior to re-  
26 transmission of repeated signals. In the preferred  
27 embodiment, all sampling and delaying of signals occurs  
28 before any detection process which might ultimately be used  
29 to bring the wirelessly transmitted information to  
30 baseband. Heterodyning (mixing) is a nonlinear operation,  
31 it preserves the linearity of the signal, whereas  
32 techniques used to ultimately demodulate a signal to

1 baseband usually result in distortion which one would not  
2 want compounded along a chain of repeaters.

3       **[0024]**       It is therefore an object of the present  
4 invention to provide a novel method of utilizing a  
5 dynamically configurable array of repeaters to facilitate  
6 multiple point-to-point communication links. It is a  
7 further object of the present invention to facilitate a  
8 mobile network who's capacity to handle calls grows  
9 automatically with the number of users in the system, such  
10 that overloads during high utilization times such drive  
11 time or at times of disaster do not occur. It is a further  
12 object of the present invention to provide more economical  
13 utilization of hardware resources in an array of repeaters  
14 to provide more economical multiple point-to-point  
15 communication links. It is a further object of the present  
16 invention to facilitate point-to-point communication  
17 between any two transceivers in a matrix of transceivers,  
18 with minimal or no reliance on ground (base) stations. It  
19 is a further object of the present invention to reduce the  
20 required transmitter power in an urban environment  
21 containing a plurality of mobile personal transceivers. It  
22 is a further object of the present invention to provide a  
23 novel method for enhanced-security military communication  
24 across or around select geographic areas.

25       **[0025]**       Other objects, features, and characteristics  
26 of the present invention, as well as the methods of  
27 operation and functions of the related elements of the  
28 structure, and the combination of parts and economies of  
29 manufacture, will become more apparent upon consideration  
30 of the following detailed description with reference to the  
31 accompanying drawings, all of which form a part of this  
32 specification.

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**Brief Description of the Drawings**

[0026] A further understanding of the present invention can be obtained by reference to a preferred embodiment set forth in the illustrations of the accompanying drawings. Although the illustrated embodiment is merely exemplary of systems for carrying out the present invention, both the organization and method of operation of the invention, in general, together with further objectives and advantages thereof, may be more easily understood by reference to the drawings and the following description. The drawings are not intended to limit the scope of this invention, which is set forth with particularity in the claims as appended or as subsequently amended, but merely to clarify and exemplify the invention.

[0027] For a more complete understanding of the present invention, reference is now made to the following drawings in which:

[0028] FIG. 1 depicts the spatial arrangement between 6 transceivers, the multiple paths that a signal takes through multiple repeaters (4 are shown) in traveling from transceiver 1 to transceiver 6, and the propagation delays associated with those paths.

[0029] FIGs. 2A and 2B illustrate the relative timing and changes in signal-to-noise ratio between signals arriving at and being retransmitted from the transceivers in FIG. 1.

[0030] FIG. 3 illustrates the summed Digital IF and rake filter in accordance with the preferred embodiment of the present invention which also incorporates time-division multiplexing.

1           **[0031]**       FIGs. 4A and 4B illustrate the equivalence  
2 between modulating the transmitter of a repeater with a sum  
3 of multiple signals (each derived as a multi-coefficient  
4 sum) and modulating the transmitter with a single composite  
5 multi-coefficient sum.

6           **[0032]**       FIG. 5 depicts an array of  
7 transceiver/repeaters according to the present invention,  
8 and the multiple guided paths that two communications take  
9 through the array.

10          **[0033]**       FIG. 6 depicts an information pulse, and  
11 time domain and frequency domain representations of an RF  
12 and IF carrier modulated by the information pulse in  
13 accordance with the present invention. In the preferred  
14 embodiment, such an information pulse is transmitted as a  
15 wireless signal. The term "wireless signal" may be used  
16 herein to refer either to a baseband information signal  
17 which is (or is to be, or has been) transmitted wirelessly,  
18 or to such a baseband information signal modulated in some  
19 fashion for transmission or processing.

20          **[0034]**       FIG. 7 depicts the receiving element, IF  
21 mixer, IF signals, A/D, tapped delay line, dynamically  
22 reconfigurable summing elements, and transmitting element  
23 within each transceiver/repeater in accordance with the  
24 preferred embodiment of the present invention where  
25 constructive summation of multi-path communication is done  
26 at an intermediate frequency (IF) through summing multiple  
27 outputs of a tapped digital delay line.

28          **[0035]**       FIG. 8 depicts the frequency and phase  
29 relationships between the local oscillator signal, received  
30 information carrier, and IF signal, and how the IF phase  
31 changes as the relative phases of the carrier and local

1 oscillator change in the preferred embodiment of the  
2 present invention.

3       **[0036]**       FIG. 9 depicts a probability density  
4 function (derived from computer simulations) for the range  
5 of possible summed values of a dual multi-path signal,  
6 where the amplitude of each wave is assumed to be unity and  
7 the relative phase between the waves is equally randomly  
8 distributed.

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#### 10       **Detailed Descriptions of some Preferred Embodiments**

11       **[0037]**       As required, a detailed illustrative  
12 embodiment of the present invention is disclosed herein.  
13 However, techniques, systems and operating structures in  
14 accordance with the present invention may be embodied in a  
15 wide variety of forms and modes, some of which may be quite  
16 different from those in the disclosed embodiment.  
17 Consequently, the specific structural and functional  
18 details disclosed herein are merely representative, yet in  
19 that regard, they are deemed to afford the best embodiment  
20 for purposes of disclosure and to provide a basis for the  
21 claims herein which define the scope of the present  
22 invention. The following presents a detailed description  
23 of the preferred embodiment (as well as some alternative  
24 embodiments) of the present invention.

25       **[0038]**       Referring first to Figure 1, depicted is the  
26 spatial arrangement between 6 transceivers TC1-TC6, and the  
27 multiple paths that a signal takes through multiple  
28 repeaters in traveling from transceiver TC1 to transceiver  
29 TC6 in the preferred embodiment of the present invention,  
30 and the propagation delays associated with those paths.  
31 The six transceivers shown in Figure 1 (TC1, TC2, TC3, TC4,  
32 TC5, and TC6) according to the present invention are

1 spatially arranged as shown. However, it is known that  
2 other arrangements are possible in accordance with the  
3 invention. Supposing that a signal is to be transmitted  
4 from TC1 to TC6 through repeater array TC2, TC3, TC4, and  
5 TC5, the signal originates at TC1 and propagates along Path  
6 2a, Path 3a, Path 4a, and Path 5a to repeater transceivers  
7 TC2, TC3, TC4, and TC5, respectively. The lengths of Path  
8 2a, Path 3a, Path 4a, and Path 5a shown in Figure 1 (e.g.,  
9 3.8, 3.7, 3.0, and 4.5 normalized length units,  
10 respectively) may be thought of as being representative of  
11 some normalized distance between transceivers, or  
12 representative of normalized propagation time of the signal  
13 along each path. Similarly, the signals will be  
14 retransmitted by repeater transceivers TC2, TC3, TC4, and  
15 TC5 along Path 2b, Path 3b, Path 4b, and Path 5b,  
16 respectively, to transceiver TC6. The lengths of Path 2b,  
17 Path 3b, Path 4b, and Path 5b shown in Figure 1 (e.g., 6.0,  
18 4.5, 7.0, and 7.2 normalized length units, respectively),  
19 like Paths 2a-5a, may also be thought of as being  
20 representative of some normalized distance between  
21 transceivers TC2-TC5 and TC6, or representative of the  
22 normalized propagation time of the signal along each path.

23 [0039] The signals received at the receivers of  
24 transceivers TC2, TC3, TC4, and TC5 are delayed, reduced-  
25 power versions of the signal transmitted from the  
26 transmitter of TC1. Since some noise power is also  
27 received at each receiver or repeater, each re-transmission  
28 results in a lowered signal-to-noise ratio in the  
29 ultimately received signal. Figures 2A and 2B illustrate  
30 the relative timing and changes in signal power between  
31 signals arriving at and being retransmitted from the  
32 transceivers in Figure 1. Transceivers TC2, TC3, TC4, and

1 TC5 have been dynamically configured to receive signals  
2 from transceiver TC1 and retransmit those signals to  
3 transceiver TC6. In a preferred embodiment of the present  
4 invention, each transceiver only needs to listen to signals  
5 from transceivers within a certain distance (or propagation  
6 time) of itself. As used herein, that distance will be  
7 referred to as that transceiver's "listen distance" (and  
8 that time will be referred to as that transceiver's "listen  
9 time"). Signals originating from transceivers positioned  
10 farther away from the destination receiver than the  
11 transceiver's listen distance are received via  
12 retransmission by intervening transceivers acting as  
13 repeaters.

14 [0040] Suppose transceiver TC1 transmits a pulse of  
15 information IPX1, having transmitted signal power P1X. As  
16 that transmitted information pulse propagates away from  
17 transceiver TC1, the signal power available for reception  
18 at the antenna of a receiver/repeater decreases with the  
19 distance the signal travels. As illustrated in Figures 2A  
20 and 2B, the IP1 pulse transmitted from transceiver TC1 at  
21 time tr2 is received by transceiver TC2 as information  
22 pulse IPR2, with reduced signal power P2R. Similarly, the  
23 IP1 pulse transmitted from transceiver TC1 at time tx1 is  
24 received by transceiver TC3 as information pulse IP3 at  
25 time tr3 with reduced signal power P3R, and received by  
26 transceiver TC4 as information pulse IP4 at time tr4 with  
27 reduced signal power P4R. If we assume that transceiver  
28 TC1 is far enough away from transceiver TC6 as to be  
29 outside the listen distance of transceiver TC6, the signal-  
30 to-noise ratio with which information pulse IPR6a is  
31 received by transceiver TC6 is too low for this signal to  
32 be directly usable, but if this information is correlated



1 with other (repeated) pulses received at transceiver TC6,  
2 it can be used to further increase overall system  
3 performance.

4       **[0041]**       In the preferred embodiment of the present  
5 invention, when an array of transceivers acts as repeaters  
6 to re-transmit a signal from an originating transceiver to  
7 a destination transceiver, each repeating transceiver  
8 applies a dynamically configured delay before re-  
9 transmission. This is done so that the repeated signals  
10 arriving at the destination receiver are aligned in a  
11 preferred way in time. Figures 2A and 2B display two  
12 possible sets of re-transmission delays, resulting in two  
13 possible time alignments of finally received pulses at  
14 transceiver TC6. In an embodiment where timing alignment  
15 is precise enough that pulses from different repeaters can  
16 be retransmitted in time to arrive aligned in time well  
17 enough to add constructively at the carrier level,  
18 coincident arrival alignment as shown in pulse group IPR6b  
19 may be preferred.

20       **[0042]**       To create such an alignment, as shown in  
21 Figure 2A, transceiver TC2 waits to retransmit information  
22 pulse IPX2 at time tx2 at power level P2X (typically  
23 similar to power level P1X, and at roughly the same signal-  
24 to-noise ratio as transceiver TC2 was able to receive  
25 information pulse IP2R) the information pulse it received  
26 at time tr2. Similarly, transceiver TC3 waits to  
27 retransmit information pulse IPX3 at time tx3 at power  
28 level P3X (typically similar to power level P1X, and at  
29 roughly the same signal-to-noise ratio as transceiver TC3  
30 was able to receive information pulse IP3R) the information  
31 pulse it received at time tr3. Similarly, transceiver TC4  
32 waits to retransmit information pulse IPX4 at time tx4 at

1 power level P4X (typically similar to power level P1X, and  
2 at roughly the same signal-to-noise ratio as transceiver  
3 TC2 was able to receive information pulse IP4R) the  
4 information pulse it received at time tr4. Similarly,  
5 transceiver TC5 waits to retransmit information pulse IPX5  
6 at time tx5 at power level P5X (typically similar to power  
7 level P1X, and at roughly the same signal-to-noise ratio as  
8 transceiver TC2 was able to receive information pulse IP5R)  
9 the information pulse it received at time tr5. The delay  
10 times that transceivers TC2, TC3, TC4, and TC5 allow to  
11 elapse before retransmitting the signals they received from  
12 transceiver TC1 are programmed such that the information  
13 pulses they transmit are received simultaneously at time  
14 tr6b at composite power level P6Rb. Although information  
15 pulses IPX2, IPX3, IPX4, and IPX5 are all re-transmitted at  
16 renewed power levels, the information from each will  
17 individually be received at the next repeater down the  
18 chain with a lower signal-to-noise ratio than transceivers  
19 TC2, TC3, TC4, and TC5 each received their information  
20 pulses. However, the summed correlated information pulse  
21 IPR6b received at transceiver TC6 may actually be received  
22 with a higher over-all signal-to-noise ration than any of  
23 the intermediate pulses IPR2, IPR3, IPR4, and IPR5 were  
24 received at intermediate transceivers TC2, TC3, TC4, and  
25 TC5, respectively.

26 [0043] In an embodiment where pulses from  
27 different repeaters cannot be retransmitted with timing  
28 accurate enough such that the retransmitted pulses arrive  
29 aligned in time to add constructively at the carrier level,  
30 but can be retransmitted with timing accurate enough that  
31 the retransmitted pulses arrive aligned in time to better  
32 than the pulse rise time associated with the information

1 bandwidth of the channel, alignment shown in pulse set  
2 IPR6c (which arrives at transceiver TC6 starting at time  
3 tr6c, at a range of power levels P6Rc) in Figure 2B would  
4 be preferred, as will be explained below.

5       **[0044]** Preferably, the retransmission delays are  
6 adjusted precisely enough to cause coherence in the  
7 received carrier signals carrying information pulses IP2  
8 through IP5, and thus the carriers reinforce each other as  
9 received by TC6. Alternatively, retransmission through  
10 times tx2, tx3, tx4, and tx5 may not be precisely aligned  
11 enough to give carrier coherence to the signals IP2R  
12 through IP5R arriving at transceiver TC6, but these times  
13 are aligned precisely enough to give good coherence to the  
14 demodulated information signal in information pulses IP2R  
15 through IP5R. In the preferred embodiment, in such a case  
16 each repeater which has been dynamically configured to  
17 retransmit signals from a first transceiver to a second  
18 transceiver may be configured to retransmit on a different  
19 carrier frequency from the rest of the repeaters re-  
20 transmitting signals from the transceiver TC1 to the  
21 transceiver TC6. Transceiver TC6 receives signals  
22 simultaneously on different carrier frequencies from each  
23 repeater and correlates the demodulated information streams  
24 received on the different carrier frequencies to derive an  
25 information signal with a higher signal-to-noise ratio than  
26 the signal-to-noise ratio of any of the individual  
27 retransmitted signals.

28       **[0045]** In another embodiment, information pulses  
29 IP2R through IP5R are retransmitted on the same carrier  
30 frequency, and delays through times are not precisely  
31 aligned enough to give carrier coherence when the  
32 retransmitted information pulses arrive at transceiver TC6.

1 In this embodiment, times tx2a, tx3a, tx4a, and tx5a  
2 through are chosen so as to stagger the arrival times of  
3 the retransmitted reduced signal-to-noise-ratio information  
4 pulses at TC6 such that no information overlap occurs (as  
5 shown in pulse group IPR6c in Figure 2B). Here, the  
6 multiple arrivals can be constructively summed through a  
7 finite-impulse-response (FIR) filter to improve signal-to-  
8 noise ratio. This FIR filter is preferably a digital FIR  
9 filter, and operates on data sampled after demodulation  
10 (detection). In another embodiment, this FIR filter  
11 operates on data sampled after down-shifting from the  
12 carrier frequency to an intermediate frequency (IF) using a  
13 mixer.

14 [0046] In the preferred embodiment, no matter  
15 whether all retransmitted pulses are retransmitted on the  
16 same carrier frequency or different carrier frequencies,  
17 and no matter whether pulses are re-transmitted to arrive  
18 coincident in time or spaced out in time, retransmission  
19 delays used in transceivers TC2, TC3, TC4 and TC5 are  
20 chosen such that the retransmission delay added by the  
21 repeating transceiver in the longest signal path (which in  
22 this example is the path through repeating transceiver TC5)  
23 is non-negative.

24 [0047] Turning now to Figure 7, depicted is a  
25 schematic representation of transceiver/repeater 700  
26 according to the preferred embodiment of the present  
27 invention. As shown, RF bursts of data 704, 705, and 706  
28 are received by transceiver/repeater 700, according to the  
29 present invention, at receiving antenna 707 staggered in  
30 time and/or frequency. Preferably, the RF signal received  
31 at antenna 707 is down-shifted in frequency by being

1 multiplied by the output of local oscillator 711 in down-  
2 shifting mixer 713, and filtered by low-pass filter 712.

3       **[0048]**       As illustrated in Figure 6, this operation  
4 modulates the frequency domain representation of the  
5 incoming information pulses. For example, incoming  
6 information pulse 601 may have frequency spectrum 604.  
7 When information pulse 601 is modulated onto carrier 602,  
8 the resulting modulated signal has frequency spectrum 605.  
9 When a signal such as 602 is received by antenna 707 (in  
10 Figure 7), down-mixed in mixer 713 and filtered by low-pass  
11 filter 712, the resulting signal might be represented by  
12 waveform 603 and spectrum 606 in Figure 6. As shown, the  
13 frequencies present in frequency spectrum 606 are in  
14 between the frequencies of the original (base band) signal  
15 of frequency spectrum 604 and the transmitted signal of  
16 frequency spectrum 605. In the preferred embodiment, these  
17 intermediate frequencies are amenable to sampling by  
18 inexpensive, readily available analog-to-digital (A/D)  
19 converters.

20       **[0049]**       Figure 8 depicts more precisely an example  
21 time and phase and frequency relationship between local  
22 oscillator signal 801, received carriers 704 and 705, and  
23 resulting IF signals 708 and 709 (which result from mixing  
24 local oscillator signal 801 from local oscillator 711 with  
25 received carriers 704 and 705, respectively, in mixer 713).  
26 In the example shown, the local oscillator 711 is set to  
27 nine tenths of the carrier frequency. Note how a small  
28 shift  $t_1$  in time of arrival between carriers 704 and 705  
29 results in a roughly 10 times greater time shift in the  
30 alignment between IF signals 708 and 709. Typically a  
31 local oscillator frequency is used that is a much smaller  
32 percentage different from the carrier frequency, so the

1 time shift magnification factor of the IF signal over the  
2 time shift (or, equivalently, phase shift) of a received  
3 carrier is even further magnified. This time magnification  
4 allows practically realizable sampling and filtering  
5 systems to digitally sample signals such as 708 and 709 and  
6 effectively actively find, track, and use the optimum time  
7 alignment for summing multiple received signals to increase  
8 effective signal-to-noise performance at the receiver.  
9 Sampling times  $ts_1$  through  $ts_7$  shown in Figure 8 are an  
10 example of sampling times which would be quite adequate to  
11 digitally correlate, align, and filter IF signals such as  
12 708 and 709, but inadequate to align phases of carrier  
13 signals 704 and 705.

14 [0050] Referring back to Figure 7, in the time  
15 domain, the signal on IF strip 721 may be thought of as a  
16 linear combination of IF signals such as 603. In  
17 particular, as depicted in Figure 7, the signal on IF strip  
18 721 may be thought of as a linear combination of IF signals  
19 708, 709, and 710, which result from signals 704, 705, and  
20 706, respectively, received at antenna 707. For example,  
21 if the periods of waveforms 704, 705, and 706 are all  $t_1$ ,  
22 then the periods of waveforms 708, 709, and 710 will all be  
23  $t_2$ , where  $t_2$  is longer than  $t_1$ . In such an example, in an  
24 embodiment where time delays may not be adjusted precisely  
25 enough to cause alignment to within a fraction of  $t_1$ , the  
26 information pulses represented by signals 704, 705, and 706  
27 are preferentially aligned in time as they arrive at  
28 antenna 707 such that they are non-coincident in time. As  
29 previously mentioned, should waveforms 704, 705, and 706  
30 align in such a way as to substantially cancel each other  
31 out at antenna 707, the resultant signal on IF strip 721

1 will also be substantially zero, and the ability to delay  
2 and repeat the received information may be impaired.

3       [0051]       Should the periods of carrier signals 704,  
4 705, and 706 be different, however (as would for instance  
5 be the case if spread-spectrum techniques are used in re-  
6 transmission), they may be allowed to arrive in any time  
7 alignment desired, because since sine waves are  
8 eigenfunctions of linear systems, no cancellation will take  
9 place either at antenna 707 or on IF strip 721. Thus, by  
10 sampling IF strip 721, all of A/D 714, FIR filter 722,  
11 retransmission summer 716, digital to analog (D/A)  
12 converter 723, retransmission (up-shifting) mixer 715,  
13 retransmission amplifier 717, and retransmission antenna  
14 718 serve an analogous function to three parallel systems  
15 where three sets of signals are received and demodulated to  
16 base band by three receivers tuned to separate frequencies,  
17 processed in three parallel FIR filters, and retransmitted  
18 on three separate antennas. This analog is true within  
19 certain limitations. For instance, if the system shown in  
20 Figure 7 received two information pulse sets from the same  
21 set of repeaters, where the two information pulse sets are  
22 on different frequencies but are aligned in time and  
23 intended to be retransmitted to different destinations,  
24 then the system could not implement the proper delays to  
25 guide transmission of one of those pulse sets to a given  
26 destination without also guiding retransmission of the  
27 other pulse set to the same destination. This limitation  
28 may, however, be overcome if correlation techniques are  
29 used to separate different frequency components of digital  
30 IF (DIF) signal, and multiple parallel FIR filters are  
31 used.

1           **[0052]**     The set of output taps 720 on shift register  
2     719 in FIR filter 722 make possible the delays between  
3     receive and transmit time pairs tr2 & tx2, tr3 & tx3, tr4 &  
4     tx4, tr5 & tx5 discussed previously and shown in Figure 2A,  
5     and receive and transmit time pairs tr2 & tx2a, tr3 & tx3a,  
6     tr4 & tx4a, tr5 & tx5a discussed previously and shown in  
7     Figure 2B. Again referring to Figures 2A, 2B and 7, the  
8     two example time alignments used to produce ultimately  
9     received information pulse sets IPR6b and IPR6c are  
10    realized by summing different output taps (such as 701,  
11    702, and 703) of shift register 719 at summing junction  
12    716. Clock signal 724 synchronously clocks shift register  
13    719 and A/D converter 714.

14           **[0053]**     The apparatus shown in Figure 7 may be used  
15    to simultaneously retransmit different sets of information  
16    pulses after applying different sets of delay and summing  
17    criteria to these different pulse sets. This is  
18    illustrated in Figure 4A (subject to the limitation  
19    previously discussed that different delays cannot be  
20    applied to different time-coincident frequency components  
21    without augmenting the apparatus shown). To demonstrate  
22    how multiple retransmission delays may be accomplished on  
23    the same channel, consider three parallel receiver/FIR-  
24    filter sets ending in summing junctions 401, 402, and 403,  
25    respectively, where the outputs of summing junctions 401,  
26    402, and 403 are further summed at summing junction 404.  
27    This combined apparatus 405 is equivalent to a single  
28    summed DIF 406, as shown in Figure 4B, feeding a single FIR  
29    filter where the set of summing coefficients 407 applied to  
30    the outputs of shift register 410 is simply the sum of the  
31    coefficients that would have been applied to the outputs of  
32    the three parallel shift registers 412, 413, and 414 in the



1 parallel FIR filters, and the final summing junction 409 of  
2 the combined FIR filter is simply the combination of  
3 summing junctions 401, 402, 403, and 404.

4       **[0054]**       In the preferred embodiment of the present  
5 invention, signals intended to be routed differently  
6 through transmitter array 500 may be time-multiplexed on a  
7 single channel, and the coefficients 408 of the combined  
8 FIR filter 411 may be cycled in time such that the routing  
9 through the array changes cyclically, and synchronously  
10 with the period of the time multiplexing. This is  
11 illustrated in Figure 3. As shown, selector circuit 300  
12 repetitively and sequentially provides enable signals e1,  
13 e2, and e3 (such that no two of e1, e2, and e3 are ever  
14 time-coincident). Enable signals e1, e2, and e3 are used  
15 to sequentially apply summing coefficients c1a, c1b, and  
16 c1c to output 301 of shift register SR4. Similar sets of  
17 time-cycled summing coefficients are applied to shift  
18 register outputs 302 and 303. Summing junction 304 is  
19 equivalent to summing junction 409. An equivalent way to  
20 implement time-cycles coefficient sets 305, 306, and 307  
21 would be to use a cyclically accessed coefficient memory to  
22 cyclically load different coefficient sets 407 in Figure 4.

23       **[0055]**       Although Figure 6 depicts the frequency  
24 spectrum of baseband rectangular information pulse and an  
25 amplitude-modulated information pulse, it will be  
26 understood by one skilled in the art that the present  
27 invention may be adapted for use with continuous (non-  
28 pulse) information signals, and any variety of modulation  
29 techniques, including but not limited to AM, FM, and  
30 Spread-Spectrum techniques. In the preferred embodiment,  
31 the information transmitted by multiple repeaters to a  
32 given destination transceiver is modulated at each repeater

1 in such a way that the multiple received signals do not  
2 cancel at the receive antenna of the destination  
3 transceiver. This may, for instance, be insured in the  
4 case of multiple received pulse-amplitude-modulated pulses  
5 on a single carrier by insuring that the pulses transmitted  
6 from the repeaters do not arrive coincident in time.  
7 Alternately, freedom from destructive interference at the  
8 receive antenna may also be assured by insuring (in pulse  
9 or continuous information transmission) that the  
10 information signals received simultaneously at a given  
11 transceiver are on different, statistically or absolutely  
12 non-overlapping frequency bands.

13 [0056] The foregoing discussion should be  
14 understood as illustrative and should not be considered to  
15 be limiting in any sense. While the present invention has  
16 been described with reference to the preferred embodiment  
17 and several alternative embodiments, which embodiments have  
18 been set forth in considerable detail for the purposes of  
19 making a complete disclosure of the invention, such  
20 embodiments are merely exemplary and are not intended to be  
21 limiting or represent an exhaustive enumeration of all  
22 aspects of the invention. The scope of the invention,  
23 therefore, shall be defined solely by the following claims.  
24 Further, it will be apparent to those of skill in the art  
25 that numerous changes may be made in such details without  
26 departing from the spirit and the principles of the  
27 invention. It should be appreciated that the present  
28 invention is capable of being embodied in other forms  
29 without departing from its essential characteristics.